Patent Application of

JianhuaWang, Qinglin Wang, Yanyan Ma, Hongtao Hou and **Alex Chun-Lai Hsu**

for

Optical Module Package

FIELD OF THE INVENTION

[0001] The invention in general relates to optical systems and methods, and in particular to optical module packages capable of operating in harsh environments.

BACKGROUND

[0002] Optical module packages holding optical or optoelectronic components are used for a variety of applications, including fiber optic communications. Such optical module packages may include fiber couplers, splitters, isolators, circulators, attenuators, switches, wavelength multiplexing or demultiplexing (WDM) components, and other optical components known in the art.

[0003] An optical module package may include a housing, one or more optical fiber cables connected to the housing, and corresponding optical fiber connectors connected at the distal ends of the cables. Each fiber cable may include an optical fiber, and a protective tube disposed over the optical fiber. Optical fibers normally require careful handling to avoid physically damaging the fibers or otherwise degrading the transmission performance of the fibers. For example, bending or stressing optical fibers can degrade the transmission properties of the fibers even if the fibers do not break. Providing adequate protection to optical fibers is of particular concern for optical module packages designed to operate in harsh environments.

SUMMARY OF THE INVENTION

[0004] In one embodiment, an optical module package comprises a housing, a plurality of optical fiber connectors; and a plurality of optical fiber cables. Each of the optical fiber cables connects the housing and a corresponding optical fiber connector. Each of the optical fiber cables comprises an optical fiber rigidly connected to the housing and to its corresponding optical fiber

connector, a flexible inner protective tube enclosing the optical fiber, and a flexible concentric outer protective tube enclosing the inner protective tube. The inner protective tube and the outer protective tube are longitudinally movable relative to the optical fiber along at least part of the optical fiber in response to environmental temperature changes, to reduce a strain on the optical fiber caused by thermal expansion of the inner protective tube and the outer protective tube.

[0005] In another embodiment, the optical fiber is capable of longitudinally moving relative to the inner protective tube, the outer protective tube, and the housing in response to environmental temperature changes. Longitudinally moving the optical fiber varies an extent of the optical fiber present in the interior of the housing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The foregoing aspects and advantages of the present invention will become better understood upon reading the following detailed description and upon reference to the drawings where:

[0007] Fig. **1-A** is a schematic diagram of an optical system including an optical module package according to an embodiment of the present invention.

[0008] Fig. **1-B** shows an optical fiber coupler package according to an embodiment of the present invention.

[0009] Figs. **2-A-F** show the proximal and distal ends of a fiber optic cable according to various embodiments of the present invention.

[0010] Fig. **3** is a schematic diagram of an optical fiber coupler package according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0011] In the following discussion, a set of elements is understood to include one or more elements. A plurality of elements includes at least two elements. Moving a first element relative to a second element encompasses moving the first element, the second element, or both. Unless specified otherwise, any recited element may be formed from multiple monolithic structures, or

may form part of a larger monolithic structure. For example, a protective tube may include multiple monolithic layers of material. Any recited connection may be a direct connection, or an indirect connection through an intermediary element. For example an optical fiber affixed or connected to a housing may be connected to the housing directly, or indirectly through a support that forms part of the housing or is situated within the housing. Unless specified otherwise, the terms proximal and distal are used to refer to relationships with respect to an optical module package housing.

[0012] The following description illustrates embodiments of the invention by way of example and not necessarily by way of limitation.

[0013] Fig. **1-A** shows a schematic diagram of an optical system **10** including an optical module package **20**, according to an embodiment of the present invention. Optical system **10** may be an optical communications system. Optical system **10** includes one or more optical source(s) **12** and one or more optical receivers **16** connected to optical module package **20** through input and output optical fibers **14, 18**. Optical module package **20** comprises a plurality of connectors **34** connected to optical fibers **14, 18**. Optical fibers **14, 18** are provided as part of optical fiber cables. In general, optical module packages such as optical module package **20** may include fiber couplers, splitters, isolators, circulators, attenuators, switches, wavelength multiplexing or demultiplexing (WDM) components, and other optical components known in the art. Generally, optical module package **20** may have one or more optical inputs, and one or more optical outputs.

[0014] Optical source **12** directs a modulated light beam through input fiber **14** to optical module package **20**, and optical receivers **16** receive the light beam after passage through optical module package **20** and output fibers **18**. The light beam may comprise multiple channels each encoding a communications signal. Source **12** may include one or more lasers or laser diodes, optical fibers, and other optical components (e.g. WDM/DWDM components) between the laser(s) and optical module package **20**. Each receiver **18** may include one or more detectors, optical fibers, and other optical components between the detector and optical module package **20**.

[0015] As shown in Fig. **1-B**, in an embodiment in which optical module package **20** is a 1x2 fiber coupler package, optical module package **20** may include a housing **24**, and various components

situated inside housing **24**. Housing **24** and the various components situated within housing **24** form a housing assembly. A fused fiber coupler **22** is affixed inside housing **24** by adhesive **26**. Fiber coupler **22** is also held in place between lateral supports **30**. Fiber coupler **22** is connected to input and output optical fibers, e.g. one input and two output optical fibers, as shown in Fig. **1-B**. A plurality of flexible optical fiber cables **32** extend through housing **24**, and terminate in corresponding optical connectors **34**. One input and two output fiber cables are shown in Fig. **1-B**. A pair of U-shaped metal stoppers (guides) **40a-b** are disposed on opposite sides of fiber coupler **22**. Each stopper **40a-b** is affixed to the outside of its corresponding optical fiber cable **32**, for example by adhesive. Each stopper **40a-b** is capable of sliding longitudinally within housing **24**. Stoppers **40a-b** extend over fiber cables **32**, so as to transversely constrain fiber cables **32.** Stopper **40a** extends over a single input cable **32**, while stopper **40b** extends over two output cables **32**. Stoppers **40a-b** constrain the outer layers of cables **32** to move only longitudinally within housing **24**. Stopper **40b** keeps its two corresponding cables **32** aligned and parallel. Stoppers **40a-b** provide added stability and strength against lateral and twisting forces applied to cables **32**. Stoppers **40a-b** may also prevent the outer cable layers from exiting housing **24**.

[0016] Each optical fiber cable **32** preferably includes an optical fiber **36**, polymeric protective tubes (covers) **46, 48** disposed concentrically around optical fiber **36**, and a sliding/support medium **50** disposed between protective tubes **46, 48**. Each protective tube **46, 48** is a loose tube that is laterally-flexible and locally longitudinally-rigid—i.e. it may bend, but does not ordinarily crumple. An inner protective tube **46** encloses optical fiber **36**, while an outer protective tube **48** encloses inner protective tube **46**. The inner diameter of protective tube **46** substantially matches the outer diameter of optical fiber **36**, such that optical fiber **36** does not bend independently of protective tube **46**, but is capable of sliding within inner protective tube **46**. Similarly, the inner diameter of protective tube **48** substantially matches the outer diameter of protective tube **46**, such that protective tube **46** does not bend independently of protective tube **48**. Sufficient space is available between the two protective tubes to fit sliding medium **50** and to allow protective tubes **46, 48** to slide relative to each other. Protective tubes **46, 48** and sliding/support medium **50** extend between connector **34** and the interior of housing **24**, through an aperture

formed in the wall of housing **24**. Protective tubes **46, 48** serve to protect optical fiber **36** from external forces that could damage optical fiber **36**. Sliding/support medium **50** serves to allow protective tubes **46, 48** to slide longitudinally relative to each other. Sliding/support medium **50** also provides additional protection to optical fiber **36**, particularly within housing **24**.

[0017] Each optical fiber **36** and its corresponding sliding/support medium **50** are affixed to housing **24** by adhesive **52**. Adhesive **52** may be placed between support protrusions **54** extending inside housing **24**. Support protrusions **54** may be integrally formed with two opposite walls of housing **24**, or may include discrete pieces attached to the inside walls of housing **24**. In some embodiments, adhesive **52** may also affix one or both of protective tubes **46, 48** to housing **24**, as described below.

[0018] Each optical fiber **36** may be a conventional fiber including a silica fiber core, a silica fiber cladding disposed around the core, and a protective polymer coating adhered to the fiber cladding. Protective tubes **46, 48** may be made of known organic substances such as polytetrafluoroethylene (PTFE, Teflon®), poly(tetramethylene glycol) poly(butylene terephthalate) (Hytrel®), unplasticized poly(vinyl chloride) (PVC-u), or other polymeric materials. Sliding medium **50** may be formed by aramid (aromatic polyamide) fibers, such as fibers made of poly-(p-phenylene terephtalamide), commonly known by the trade name Kevlar®. Housing **24** may include one or more suitable materials such as metals (e.g. aluminum) or plastics. Adhesive **52** may be an epoxy. Stoppers **40** may be formed of a metal such as aluminum, or other rigid materials.

[0019] Each optical fiber cable **32** may have a length on the order of centimeters to meters or longer, for example about 3-10 m. Each optical fibers **36a-b** may have diameters on the order of hundreds of μm, for example about 250 μm. Protective tubes **46, 48** may have diameters on the order of hundreds of μm to mm. In an exemplary implementation, inner protective tube **46** has an outer diameter of about 900 μm (~1 mm), while outer protective tube **48** has an outer diameter of about 3 mm. In an exemplary embodiment, housing **24** has a length on the order of a few cm, and a width and height of about 1 cm.

[0020] To assemble optical module package **20**, any internal optical components (e.g. fiber coupler **22**) are positioned within housing **24**, and optical fibers **36** are inserted through their corresponding apertures in the walls of housing **24**. Protective tubes **46, 48** and sliding/support media **50** are slid over optical fibers **36**. Stoppers **40a-b** are secured to outer tubes **48**, and sliding/support media **50** and optical fibers **36** are secured to housing **24**. Connectors **34** are assembled at the distal ends of optical fibers **36**.

[0021] Fig. **2-A-F** illustrate a number ways of designing and connecting an optical fiber cable having two movable protective tubes, according to various embodiments of the present invention. Fig. **2-A** shows a longitudinal sectional view of the distal and proximal regions of an optical fiber cable **32**, and a connector **34** connected to cable **32** along a distal region of cable **32**, according to an embodiment of the present invention. In the illustrated embodiment, inner protective tube **46** is free to move at its distal end, while outer protective tube **48** is free to move at its proximal end.

[0022] Connector **34** may be a conventional fiber optic connector such as a Seiko Instruments SMU-P Series MU connector. For clarity, an exemplary connector **34** is illustrated in Fig. **2-A** schematically. A conventional connector may include features such as outer keyed protrusions for mating the connector externally, a longitudinal spring for allowing a connector casing to move relative to a connector ferrule or fiber, and/or a spring cover (spring push) for pressing the spring against the ferrule. Various connector designs suitable for use in embodiments of the present invention are known in the art.

[0023] Connector **34** includes a crimp ring **58** having a proximal tubular aperture sized to fit over outer protective tube **48**, and a distal tubular aperture sized to fit over a ferrule **62** or another fixed connector structure (e.g. a spring cover). Crimp ring **58** secures optical fiber cable **32** to connector **34**. The two opposite-facing apertures of crimp ring **58** are separated by an annular stop which abuts a transverse surface of outer protective tube **48**. Inner protective tube **46** passes through a central aperture defined in the annular stop of crimp ring **58**. Ferrule **62** is disposed over optical fiber **36**. A connector casing **66** is disposed over ferrule **62**. A connector boot **64** is disposed over crimp ring **58** and outer protective tube **48**. Boot **64** provides additional protection to optical fiber **36**, and prevents excessive bending of cable **32**.

[0024] An annular gap **68** divides inner protective tube **46** into longitudinally-separated proximal and distal parts. Each of the proximal and distal parts is itself a protective tube. Preferably, gap **68** is situated within boot **64**, to minimize any loss of stability or fiber protection due to gap **68**. Generally, one or more gaps such as gap **68** may be situated outside of boot **64**, particularly if a relatively long cable is employed. Gap **68** preferably has a length sufficient to accommodate the thermal expansion of inner protective tube **46** relative to optical fiber **36**. At the same time, gap **68** is preferably not so wide as to compromise the protective properties of inner protective tube **46**. In an exemplary embodiment, gap **68** has a length on the order of mm, preferably about 1-10 mm, for example about 4 mm. An optimal length for gap **68** may depend on the length of inner protective tube **48**, the number and positioning of any other gaps, and the thermal expansion coefficients of inner protective tube **48** and optical fiber **36**.

[0025] Inner protective tube **46** is secured at its proximal end to housing **24** by adhesive or a fastener. Sliding medium **50** is secured at its proximal end to housing **24**, and at its distal end to connector **34**. Sliding medium **50** may be secured at its proximal end by adhesive, and at its distal end by crimp ring **58**. The proximal end of outer protective tube **48** is free to move longitudinally within housing **24**, together with and constrained by stopper **40**. The distal end of outer protective tube **48** is fixed within connector **34** crimp ring **58**. Both inner protective tube **46** and outer protective tube **48** are capable of sliding longitudinally with respect to optical fiber **36** as the environmental temperature around cable **32** changes. Preferably, differential thermal expansion does not impart significant stresses on optical fiber **36** within a temperature range of -40 °C to +85 °C.

[0026] Table 1 shows approximate thermal expansion coefficients (CTEs) for a number of materials suitable for use in the present invention:

Table 1

Material	CTE
SiO_2	~5×10^{-7}/°C
polytetrafluoroethylene (PTFE, Teflon®)	~9.9×10^{-5}/°C
poly(tetramethylene glycol) poly(butylene terephthalate) (Hytrel®)	~6.5×10^{-5}/°C
unplasticized poly(vinyl chloride) (PVC-u)	~7×10^{-5}/°C
various other polymeric materials	~$40\text{-}200 \times 10^{-6}$/°C

[0027] The exemplary numbers shown in Table 1 are not intended to limit the scope of the present invention. As Table 1 shows, polymeric materials generally have thermal expansion coefficients one to two orders of magnitude higher than silicon dioxide. For a conventional silicon dioxide optical fiber **36**, the thermal expansion coefficient of the optical fiber (formed by the optical fiber core, cladding, and coating) may be similar to that of the silicon dioxide core and cladding alone. Generally the thermal expansion coefficient of a silicon dioxide optical fiber is lower than that of polymeric materials. For an optical fiber cable having a length of 1 m, a temperature change of 100 °C could yield a change in the protective tube length on the order of several mm to cm. Over the same temperature range, the optical fiber itself may change by less than 1 mm. Optical module package **20** is preferably capable of operating over such a wide temperature range without degrading the performance of the optical fiber.

[0028] Allowing outer protective tube **48** to move at its proximal end, within housing **24**, rather than within connector **34** or between connector **34** and housing **24**, may provide increased stability and protection to optical fiber **36**. Allowing inner protective tube **46** to move at its distal end, within connector **34**, may reduce assembly problems by providing improved access to inner protective tube **46** during its connection at the movable end. If the end of inner protective tube **46** were to slide within outer protective tube **48** during assembly, retrieving the end of inner protective tube **46** may be easier at the distal end of cable **32** than within housing **24**.

[0029] Fig. **2-B** shows a longitudinal sectional view of the distal and proximal regions of an optical fiber cable **132**, and a connector **134** connected to cable **132** along a distal region of cable **132**, according to an embodiment of the present invention. Optical fiber **36** is enclosed by two concentric, continuous, inner and outer protective tubes **146, 148**, respectively. Inner

protective tube **146** and sliding medium **50** are affixed at their distal ends to an optical fiber connector **134**. The proximal end of inner protective tube **146** is free to slide longitudinally with respect to optical fiber **36** and outer protective tube **148**, so as to accommodate changes in the length of inner protective tube **146** due to thermal expansion. The proximal ends of outer protective tube **148** and sliding medium **50** are affixed to housing **24**. The distal end of outer protective tube **148** is free to move longitudinally with respect to optical fiber **36** and inner protective tube **146**, so as to accommodate changes in the length of outer protective tube **148** due to thermal expansion. A stopper **140** is secured to the outside outer protective tube **148**, for ensuring that outer protective tube **148** does not slide out of connector **34**. Stopper **140** is free to move longitudinally within a limited range within a connector boot **164**. A longitudinal gap **168** is provided between the distal transverse end surface of outer protective tube **148** and the transverse surface of connector boot **164** facing the distal transverse end surface of outer protective tube **148**. A crimp ring **158** as described above is used to secure inner protective tube **146**, but not outer protective tube **148**.

[0030] Fig. **2-C** shows a longitudinal sectional view of the distal and proximal regions of an optical fiber cable **232**, according to another embodiment of the present invention. A connector **34** as described above is connected to cable **232** along a distal region of cable **232**. Cable **232** is similar to the cable **32** described with reference to Fig. **2-A**, except that the proximal end of inner protective tube **46** is free to move rather than fixed.

[0031] Fig. **2-D** shows a longitudinal sectional view of the distal and proximal regions of an optical fiber cable **332**, according to another embodiment of the present invention. Cable **232** is similar to the cable **32** described with reference to Fig. **2-A**, except that it includes a continuous inner protective tube **146** having its distal end fixed with respect to connector **34**, and its proximal end free to move with respect to optical fiber **36** and outer protective tube **48**.

[0032] Fig. **2-E** shows a longitudinal sectional view of the distal and proximal regions of an optical fiber cable **432**, according to yet another embodiment of the present invention. Cable **432** includes an inner protective tube **446** and an outer protective tube **448** which are free to move at

their distal ends, and fixed at their proximal ends. An annular gap **468**, situated within a connector **434**, accommodates the thermal expansion of protective tubes **446, 448**.

[0033] Fig. **2-F** shows a longitudinal sectional view of the distal and proximal regions of optical fiber cable **432**, according to still another embodiment of the present invention. In the embodiment illustrated in Fig. **2-F**, both proximal and distal ends of both protective tubes **446, 448** are free to move. An annular gap **468** accommodates the thermal expansion of protective tubes **446, 448** relative to optical fiber **36**. Guides **40, 140** are provided at both ends of cable **432**, within housing **24** and connector **434**.

[0034] Fig. **3** shows a fiber coupler optical module package **820** according to another embodiment of the present invention. The configuration of Fig. **3** may be used for optical components other than fiber couplers, as described above. A fused fiber coupler **822** is affixed inside a housing **824** by adhesive **826**. Fiber coupler **822** is also held in place between lateral supports **830**. Fiber coupler **822** connects an input fiber **836a** to two output fibers **836b-c**. A plurality of external optical fiber cables **832a-c** extend through housing **24**, and terminate in corresponding optical fiber connectors situated outside housing **24**. In general, the optical fiber connectors may have any of the configurations described above with respect to Figs. **2-A-F**. Preferably, the optical fiber connectors are rigidly connected to the various optical fiber cable layers/components described below.

[0035] Each optical fiber cable **832a-c** includes a corresponding optical fiber **836a-c**. The following discussion focuses on an exemplary optical fiber cable **832a**. Optical fiber cables **832b-c** are preferably identical to optical fiber cable **832a**. Optical fiber cable **832a** includes polymeric protective tubes (covers) **846a, 848a** disposed concentrically around optical fiber **836a**, and a sliding/support medium **850a** disposed between protective tubes **846a, 848a**. An inner protective tube **846a** encloses optical fiber **836a**, while an outer protective tube **848a** encloses inner protective tube **846a**. Protective tubes **846a, 848a** and sliding medium **850a** are affixed to housing **24** by adhesive **852a, 852a'**. A first adhesive mass **852a** secures outer protective tube **848a** to housing **24**, while a second adhesive mass **852a'** secures inner protective tube **846a** and sliding medium **850a** to housing **24**. Optical fiber **832a** is free to move longitudinally with

respect to protective tubes **846a, 848a**. Preferably, the distal ends of protective tubes **846a, 848a** are also secured to corresponding optical fiber connectors. Securing both ends of protective tubes **846a, 848ab** may provide increased stability and robustness to optical module package **820**.

[0036] A plurality of parallel guide rails **880** are disposed within housing **824** so as to constrain the internal position of optical fibers **836a-c** within housing **824**, as fibers **836a-c** move with respect to housing **824**. The shape of each optical fiber **836a-c** within housing **824** includes at least one bend or loop for accommodating the optical fiber **836a-c**, as the length of the optical fiber **836a-c** within housing **824** changes, for example in response to environmental temperature changes. Alternative positions for fibers **836a-c** are shown by the dashed lines **882a-c**, respectively. Guide rails **880** and fiber coupler **822** constrain the orientation of each fiber **836a-c** at least two laterally-separated locations separated by a bend. The orientation of each fiber **836a-c** at one of the constraint locations is opposite to the orientation at the other constraint location. Guide rails **880** serve to prevent fibers **836a-c** from touching the walls of housing **24**, thus reducing the force needed to confine fibers **836a-c** within housing **24**. If fibers **836a-c** were allowed to move freely laterally within housing **24**, contact with housing **24** could lead to degradation of the transmission properties of the fibers.

[0037] It will be clear to one skilled in the art that the above embodiments may be altered in many ways without departing from the scope of the invention. For example, a sliding medium is not necessarily required between the inner and outer protective tubes. Various materials other than the ones exemplified above may be used for optical fibers, protective tubes, and sliding media. Multiple gaps or cuts may be provided within one or more of the protective tubes, particularly for long optical fiber cables. An optical module package may be connected to MxN optical fiber cables, where M, N >0. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.